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Description of the advertisement call of *Boulenophrys nanlingensis* (Anura, Megophryidae), with a case of individual identification using its dorsum pattern

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Abstract

We describe the advertisement call of the Nanling horned frog, *Boulenophrys nanlingensis* for the first time, based on recordings obtained from four individuals. One of these individuals, which was identified using its dorsum pattern, was recorded twice after nine months. Distinct shifts in the temporal parameters and call rate were observed from calls of the re-captured individual, which was suspected to be related to temperature and social context. However, due to the limited sample size, further research is needed to confirm these findings. We highlight the potential of mark-recapture method using dorsum pattern for studying and monitoring the Nanling horned frog and other megophyinid frogs.

Key Words

bioacoustics, frogs, mark-recapture, Megophryinae, southern China

Introduction

The genus *Boulenophrys* Fei, Ye & Jiang, 2016 is the largest branch of the Asian horned frog subfamily Megophryinae Bonaparte, 1950, comprising 65 species found in southern China and the Indochina peninsula (Frost 2023). During their breeding season, male *Boulenophrys* frogs emit repeated, monosyllabic calls from stream banks and often form small chorus groups (Pope 1931; Liu 1950; Wang et al. 2014). These calls are species-specific, with clear differences particularly evident amongst sympatric species (Liu et al. 2018; Cutajar et al. 2020). As a result, call parameters have become a diagnostic character in recent taxonomic studies for identifying *Boulenophrys* species (Tapley et al. 2017, 2018, 2020).

Boulenophrys nanlingensis (Lyu, Wang, Liu & Wang, 2019) is distributed throughout Nanling Mountains in southern China. According to Wang et al. (2019), the breeding season of *B. nanlingensis* was from August to December. Notably, this period contains seasonal changes with the air temperature decreasing during this period in southern China. Although the advertisement call of *B. nanlingensis* was not described, a recently published guide, "A Field Guide to the Amphibians of Eastern China" (Ding et al. 2022), has illustrated its spectrogram and oscillogram and provided an audio file for field identification. Thus, we could easily identify this species in the field from its distribution area.

Methods

Field observation

On 18 November 2021, during a night survey conducted in Mangshan (also known as Mt. Mang), Yizhang County,

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Hunan Province, China (24.945°N, 112.938°E, ca. 1220 m elev.), we observed a group of at least five male *B. nanlingensis* calling in chorus on rocky areas along the bank of a mountain stream. The stream was approximately 5 m wide and several individuals of *Leptobrachium liui* could also be heard calling nearby. We were able to locate four individual frogs of *B. nanlingensis*, three of which were hiding under a crevice with their feet submerged in shallow water, while one remained hidden under fallen leaves. Each individual was positioned at least 1 m apart from the others. We recorded their advertisement calls individually between 20:30 and 22:00 h and captured and photographed two of them next to an improvised scale bar (the shotgun microphone). Both were released immediately after photographing.

After nearly nine months, when we revisited this site during a night survey on 13 August 2022, a single calling male *B. nanlingensis* was located under a crevice about 5 m from the rocky areas which we visited in November 2021. After recording its advertisement call between 20:00 and 20:30 h, we captured the frog and held it in captivity for a few days before releasing it back to the collection site on 18 August 2022. During this period, we took measurements and photographs of the frog. Upon comparing photos taken during both surveys, we confirmed that this frog belongs to one of the photographed individuals we had encountered in November 2021 (see Results).

Data collection

During our initial survey, the calls were recorded by using a Zoom F6 digital sound recorder with a Boya BM6060L shotgun microphone, held approximately 0.2–1 m from each frog. Two recordings from four individuals (vocally marked as No.1–4 in the recordings) were made at a sample rate of 192 kHz and a resolution of 24-bit. The ambient air temperature was recorded as 12.3 °C by using a digital thermometer (0.1 °C, AZ Instrument 8918). For the second survey, we used a Zoom F3 digital sound recorder with a Sennheiser ME66/K6 shotgun microphone held approximately 0.5 m from the frog. A single recording was made at 192 kHz sampling rate and 32-bit float resolution. The air ambient temperature was recorded as 19.7 °C.

The snout-vent length (SVL) of the re-captured individual was measured by using a digital caliper (0.01 mm, to the nearest 0.1 mm). We also estimated the SVL of the two photographed frogs in November 2021 by measuring the columns on the shotgun microphone.

Acoustic analysis

All recordings obtained from the field were resampled to 44.1 kHz and 16-bit by using Adobe Audition 2023 and were then analysed with Raven Pro v.1.6.4 (K. Lisa Yang Center for Conservation Bioacoustics 2023). Spectrogram measurements were taken as follows: Hann window, DFT = 512 samples, overlap = 50%, Hop Size = 256 samples. We used "call-centred" terminology as summarised by Köhler et al. (2017), in which the fundamental unit was defined as a "call" and the continuous units were defined as a "call group". The following acoustic parameters were measured: call duration (ms); call interval (ms); number of calls per call group; call repetition rate (calls/s), measured by counting the total number of calls (k) within a call group and dividing k-1 by the duration between the onset of the first call and the onset of the last call of the call group (modified from Bee et al. (2013)); number of pulses per call; dominant frequency (Hz), measured using the function "Peak Frequency" in Raven Pro. We also reported the frequency bandwidth (Hz) by measuring frequencies 5% and 95%. The spectrogram and oscillogram figures were generated using Seewave v.2.2.0 (Sueur et al. 2008) and TuneR 1.4.2 (Ligges et al. 2013) packages in R programme 4.2.2 (R Core Team 2021) with a "Hanning" window size of 256 samples and an overlap of 50%.

Results

The photos from the re-captured individual that were taken in both surveys are shown in Fig. 1. Multiple colour patterns and morphological characters (enlarged tubercles) indicate that the two photos belong to a same frog.

Measurements of acoustic parameters of the four individuals are shown in Table 1, the recaptured individual being marked as "No. 3". The advertisement call of

Table 1. Call parameters of *Boulenophrys nanlingensis*. N = number of call groups/calls analysed, NM = not measured.

Individuals	No. 1 (N = 18/138)	No. 2 (N = 15/171)	No. 4 (N = 4/35)	No. 3 (N = 10/116)	No. 3 (N = 7/135)
Recording date	18 Nov 2021	18 Nov 2021	18 Nov 2021	18 Nov 2021	13 Aug 2022
Air temperature (°C)	12.3	12.3	12.3	12.3	19.7
SVL (mm)	NM	NM	ca. 34	ca. 33	37.3
Condition	Chorus	Chorus	Chorus	Chorus	Solo
Call duration (ms)	169.3±18.3(73.5–196.8)	196.9±21.2(74.0–268.0)	199.2±26.7 (94.7–298.6)	176.9±21.6 (96.4–248.6)	101.6±8.1 (60.2–113.6)
Call interval (ms)	584.5±206.9 (295.9–1313.1)	513.9±150.3 (185.1–1030.2)	526.3±138.0 (376.1–819.0)	548.6±165.2 (321.9–1129.5)	195.0±34.8 (137.8–348.3)
Dominant frequency (Hz)	3448±237 (2412–4307)	3366±91 (3187–3704)	3411±92 (3359–3618)	3285±86 (3101–3445)	3276±96 (3187–3618)
Frequency 5% (Hz)	3008±213 (2067–3273)	3123±106 (2153–3187)	3102±186 (2326–3187)	2978±275 (2067–3187)	2712±282 (1378–3015)
Frequency 95% (Hz)	4284±145 (3445–4479)	3969±123 (3618–4393)	4243±79 (4048–4393)	3968±232 (3618–4737)	4179±100 (3790–4393)
No. of pulses per call	21.7±1.7 (14–28), N=133	22.5±1.9 (15–26), N=166	23.1±1.3 (20–26), N=32	20.5±1.7 (15–25), N=116	22.6±1.9 (13–28), N=124
No. of calls per call group	7.7±1.9 (4–11)	11.4±6.4 (5–32)	8.8±4.3 (5–15)	11.6±5.2 (4–18)	19.3±5.2 (14–29)
Call repetition rate (calls/s)	1.4±0.2 (1.0–1.8)	1.4±0.2 (1.0–1.6)	1.3±0.2 (1.2–1.7)	1.4±0.1 (1.1–1.6)	3.4±0.1 (3.3–3.6)

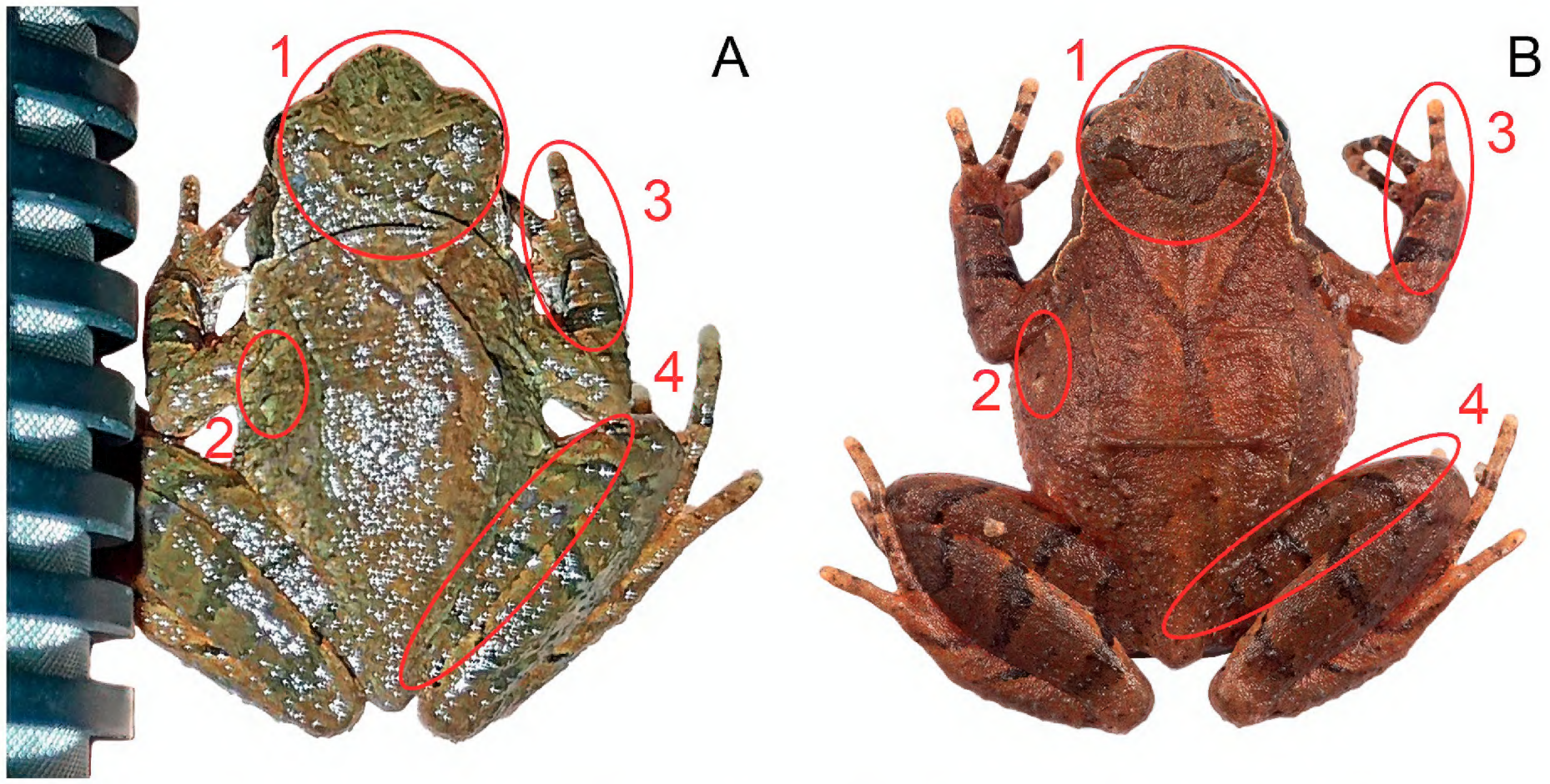

Figure 1. Comparison of the photos taken in November 2021 (**A**) and August 2022 (**B**) from the re-captured individual of *B. nanlingensis*. Red circles showing characters used for individual identification: (1) triangle pattern between upper eyelids, (2) prominent tubercles on upper left flank, (3) black bands on lower right arm and right fourth finger and (4) five black bands on right outer thigh. Images not to scale.

B. nanlingensis is a group of repeated pulsative calls. Call amplitude was consistent within each call group, except for the first 1–2 calls which had a lower amplitude. Within each call, the first pulse begins with a moderate amplitude, followed by a distinct interval. The second pulse experiences a sudden increased amplitude modulation, which then gradually increases to reach its peak amplitude at approximately 1/3 of the way through the call. The amplitude then gradually decreases to the end of the call.

The mean value of call duration amongst individuals recorded in November 2021 varied from 169.3 ms to 199.2 ms and the mean value of call interval varied from 513.9 to 584.5 ms. However, these values obtained from the re-captured individual recorded in August 2022 were considerably shorter (101.6 ms and 195.0 ms, respectively). As a result, this individual exhibited a much higher mean call repetition rate of 3.4 calls/s, compared to the calls recorded in November 2021 (1.3–1.4 calls/s). Fig. 2 demonstrates the differences in calls recorded from the re-captured individual "No. 3" between different seasons.

Discussion

According to Qian et al. (2023), *Boulenophrys nanlingensis* is in sympatry with *B. shimentaina* and *B. ombrophila* in Mangshan, while the dominant frequency of the advertisement call of *B. nanlingensis* (2.3–4.1 kHz) is lower than that of *B. shimentaina* (vs. 4.7–5.2 kHz; Lyu et al. (2020)), but overlapped with that of *B. ombrophila* (3.5–3.6 kHz; Messenger et al. (2019)). However, during our surveys in 2021 and 2022, we consistently observed *B. ombrophila* ceased its calling activities by mid-June. Thus, since *B. nanlingensis* breeds from August to December, it is unlikely that these two species with overlapping dominant frequencies will be present at the same time of the year.

Compared to the published calls of the other species in *Boulenophrys*, the advertisement call of *B. nanlingensis* differs considerably, reinforcing the specific identity of this taxon. For example, the call duration of *B. nanlingensis* (60.2–298.6 ms) is longer than that of *B. fansipanensis* (34.0–49.0 ms; Tapley et al. (2018)), *B. frigida* (43.0–50.0 ms; Tapley et al. (2021)) and *B. boettgeri* (54.0 ms, mean value; Wang et al. (2014)). The number of pulses per call of *B. nanlingensis* (13–28) is larger than that of *B. frigida* (10–11; Tapley et al. (2021)). The call repetition rate of *B. nanlingensis* (1.0–3.6 calls/s) is lower than that of *B. boettgeri* (5.0 calls/s, mean value; Wang et al. (2014)), *B. huangshanensis* (4.1 calls/s, mean value; Wang et al. (2014)), *B. jinggangensis* (5.7 calls/s, mean value; Wang et al. (2014)) and *B. minor* (4.0 calls/s, mean value; Jiang et al. (2002)).

Temperature has been reported to affect temporal parameters and call rates in most anurans (reviewed in Gerhardt (1994)). In this study, we observed distinct shifts in temporal parameter (i.e. call duration and call interval) and call rate from the recaptured individual, whose calls were recorded twice during different seasons. A similar result was reported from another megophryinid frog *Ophryophryne elfina*, whose calls were recorded at different temperatures (11.3 °C and 17.5 °C, Poyarkov et al. (2017)). However, the social context was also related to call rate shift (Capshaw et al. 2020). During our first encounter, the frogs were calling in a chorus with several conspecific males. We have noticed that these individuals would adjust their call rhythm by lengthening the call interval to avoid overlapping when other males attempted

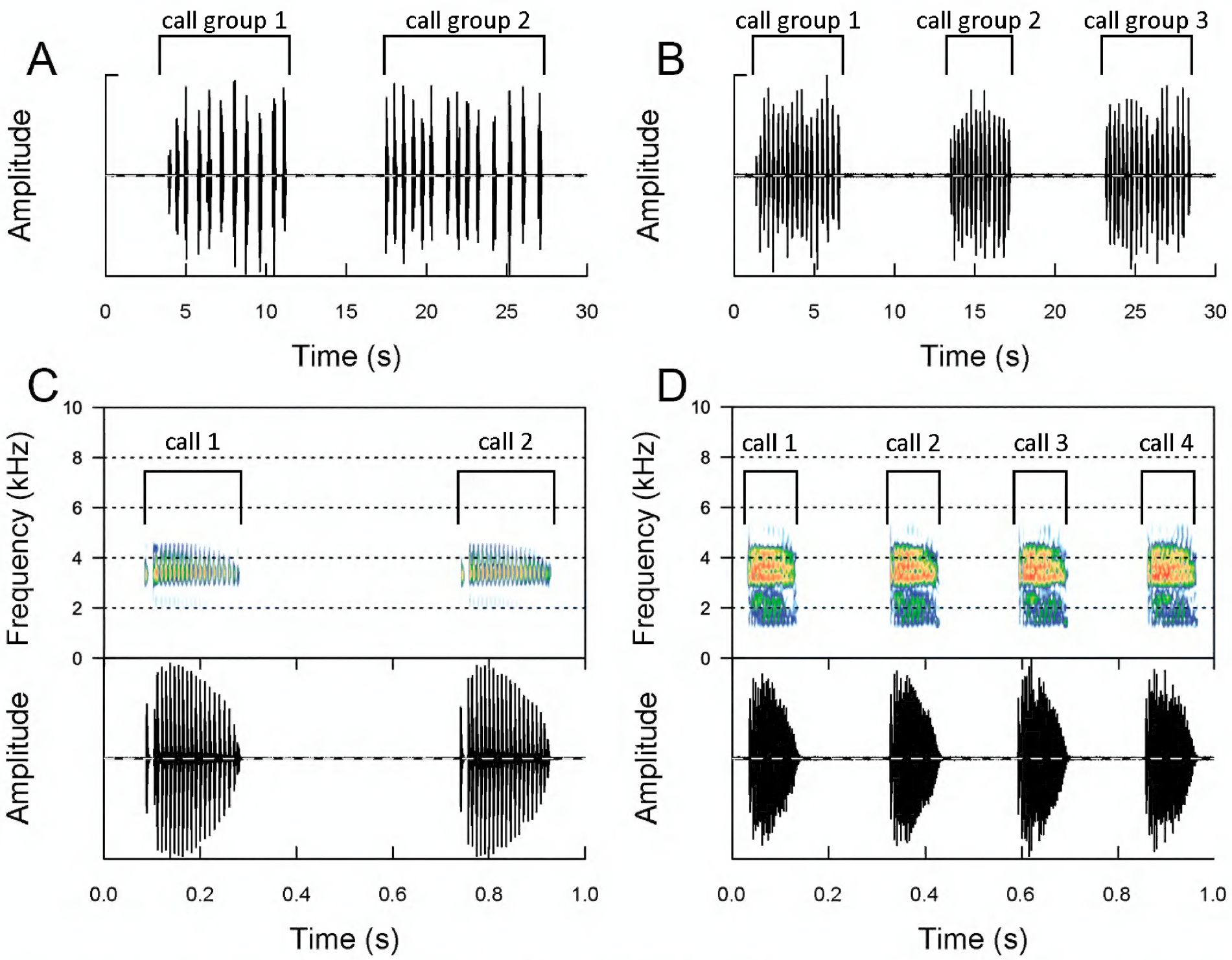

Figure 2. Comparison of the advertisement call of a recaptured individual of *B. nanlingensis* recorded from November 2021 (**A, C**) and August 2022 (**B, D**). 30 s oscillograms showing two call groups recorded in November (**A**) and three call groups recorded in August (**B**). 1 s oscillograms and corresponding spectrograms showing two calls recorded in November (**C**) and four calls recorded in August (**D**).

to join the chorus. However, during the second encounter, the frog was calling alone.

Several megophryinid frogs are known to be exhibit loyalty to their breeding habitats or calling sites. For instance, Liu (1950) observed that *B. omeimontis* "*This frog has the special habit of appearing on the same stone near the margin of the water every night*", while Mulkmus et al. (2002) reported that *Pelobatrachus baluensis* frogs "*live in very stationary calling communities*" and *P. kobayashii* frogs "*live in permanent colonies*", with five colonies of *P. baluensis* traced by Mulkmus et al. (2002) from same spots over five years. In our study, we observed a potentially similar pattern of loyalty to breeding habitats in the recaptured individual of *B. nanlingensis*, which did not move its calling site more than 5 m over a nine-month period.

The mark-recapture method has been long and widely used in amphibians in demographic, home range, behaviour and other aspects of studies (e.g. Martof (1953); Zweifel (1968); Nelson and Graves (2004); Pettitt et al. (2013)). Toe-clipping was previously the most frequently used method to mark an individual, but was reported to be harmful to individuals or influence their behaviour (reviewed in Wells (2007)). To avoid such unexpected consequences, non-invasive methods, such as individual recognition, based on colour patterns, were proposed (Bradfield 2004; Kenyon et al. 2009; Zheng et al. 2011; Caorsi et al. 2012; Morrison et al. 2016; Patel and Das 2020). Although only one individual from *B. nanlingensis* was tested in this study, we have found that its dorsal pattern and prominent skin tubercles did not show obvious changes over a nine-month period. We propose that this method could potentially be a useful non-invasive tool for studying or monitoring Nanling horned frogs and other megophryinid species which having distinct dorsum patterns (as well as ventral patterns, which were not recorded in this study) that varied between individuals.

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